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050127

Mechanical Behavior of Fabric-Film Laminates

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Introduction

Inflatable structures are gaining wide support in planetary scientific missions as well as commercial applications. For such applications a new class of materials made of laminating thin homogenous films to lightweight fabrics are being considered as structural gas envelopes. The emerging composite materials are a result of recent advances in the manufacturing of lightweight, high strength fibers, fabrics and scrim. The lamination of these load-carrying members with the proper gas barrier film results in a wide range of materials suitable for various loading and environmental conditions. Polyester-based woven fabrics laminated to thin homogenous film of polyester (Mylar) is an example of this class. This fabric/film laminate is being considered for the development of a material suitable for building large gas envelopes for use in the NASA Ultra Long Duration Balloon Program (ULDB). Compared to commercial homogenous films, the material provides relatively high strength to weight ratio as well as better resistance to crack and tear propagation. The purpose of this paper is to introduce the mechanical behavior of this class of multi-layers composite and to highlight some of the concerns observed during the characterization of these laminate composites.

Background

Scientific Balloons are large structures used as platforms to conduct scientific research at the upper atmosphere^{1,2}. Their success is measured by their performance in three areas: maximum payload weight the balloon is able to lift to the upper atmosphere, maximum attainable altitude; and mission duration at target altitude with minimum altitude excursion. For long duration flights, those on the order of several weeks, the balloon is sealed to prevent the escape of the lifting gas. As the temperature of the balloon rises due to the surrounding environmental conditions, the structural material must be sufficiently strong to withstand the stresses caused by the increasing pressure of the expanding gas. On the other hand, at the lowest temperature, positive differential pressure is also maintained to maintain the balloon volume and thus preventing it from descending due to the night's cold temperatures. Thin films of Mylar and nylon have been used in the past because of their high strength to weight ratio³. However, thin films of these high strength materials exhibited three major problems. First, they develop pinholes upon folding and storing, a potential source for failure. Second, they provide little or

no resistance to crack propagation, in particular at low temperatures (temperature can be as low as -80°C or colder) during a typical flight. Third, they tend to fail at the seams most likely due to the failure of the adhesive used to join the balloon gores under the conditions of low temperature and high internal pressure achieved during a typical flight. The first two situations are typical for Mylar and the third is typical for nylon. These problems, therefore, can compromise the success of the mission and increase the likelihood of catastrophic failures.

To achieve the level of strength required for these super pressure systems and to avoid or minimize the above problems, lightweight woven fabrics are incorporated as a load-carrying member. The availability of wide range of these fabrics and films can provide means to develop structures suitable for wide range of applications. This work will provide a brief introduction to the mechanical behavior of these multi-layer systems.

Materials & Data Acquisition

The material used in this study is a bi-laminate of woven polyester fabric and thin homogenous film of polyester (DuPont Mylar type A). The fabric has a natural color; it is made using high tenacity polyester yarn. The warp is constructed using 30 denier, 12 filaments, 122 count resulting in a fabric strength of 3660 denier per inch (DPI). The fill is constructed using 30 denier, 12 filaments, 108 count resulting in a fabric strength of 3240 denier per inch (DPI). The fabric is designed with rip stop polyester yarn running in both the machine and transverse directions at spacing of 9.65 mm (0.38 inches) from one another. The net fabric weight is 30.18 g/m² (0.89 oz/yd²).

The fabric when laminated to 6.35 microns (0.25 mil) mylar results in a total weight of 45.77 g/m² (1.35 oz/yd²) and is given the notation DP 6611.25. The excess weight over the weight of the fabric and film is due to the polyester laminating adhesive.

The uniaxial measurements were conducted on a standard Electro-mechanical testing machine, Instron model 4505 in accordance with ASTM standard test method⁴. The uniaxial measurements were made in orthogonal orientations: machine (MD) and transverse (TD) directions.

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All tests were conducted at a cross-head displacement (CHD) of 76.2 mm/min except for the rate dependent tests; the gauge length of the specimen was also 76.2 mm resulting in a 100% strain per minute.

Results and Discussions

The mechanical behavior in the machine direction (MD) measured at 23, -30 and -80°C is shown in Figure (1), that in the transverse direction is shown in Figure (2). The curves shown are the average data from each sample. The following comments can be made about the figures: The break load increases as the temperature decreases. It is also evident that, the apparent elastic (linear) region increases as the temperature decreases. The effect of geometry due to the interlocking yarns in both directions as shown in the first portion of the curves, is more evident at room temperature than at the lower temperatures. This is likely due to the pretension of the specimens that usually occurs when measuring at sub zero temperatures. The upward behavior prior to break in the transverse direction case at -30°C is interesting, it indicates some strain hardening taking place contrary to all other cases, this behavior is real it was seen in all the individual curves for this sample. It is likely that some transition or physical phenomenon is taking place at this particular temperature and warrants further investigation. It is also evident that, in both cases, MD and TD, the maximum percent strain decreased as the temperature decreased, as expected.

The effect of testing rate on the mechanical properties of DP 6611.25 is shown in Figure (3). The effect was studied over five decades ranging from 0.0762 mm/min to 762 mm/min. All testing was conducted at room temperature on specimens cut in the machine direction (MD). The fact that the mechanical behavior depends on the testing rate suggests that the bi-laminate composite is visco-elastic. This visco-elastic behavior indicates that the deformation of the polymer specimen is reversible but time dependent, it is associated with the distortion of polymer chains from their equilibrium conformations through activated segmental motion involving rotation about chemical bonds. The contribution of each layer to this behavior in a multi-layers structure is quite difficult to assess due to the fact that in a typical flight there are many possible stress systems, which may be set up due to a mechanical load. Just to name a few, uniaxial and biaxial loading of the film, fabric^{3,4} as well as the individual fibers and filaments; a shear loading on the adhesive layer in the composite; flexural loading that may contain tensile, compressive and shear components. For that reason we are considering the gross behavior of the structure rather than a detailed analysis. This limited investigation along with other data currently being obtained under biaxial loading conditions should provide

enough information for a simple structural model valid for these multi-layer composites.

Conclusions

Fabric-film laminates are an important class of material that evolved due to recent advances in the manufacturing of yarns and fabrics. Due to the wide selection of available yarns and films in the commercial markets, they can provide a wide range of properties suitable for various applications. The mechanical behavior of a typical case is shown. The results show large dependency on temperature as well as loading rate. Detailed investigations on the behavior of these materials are needed due to their expected growth in the immediate future.

References

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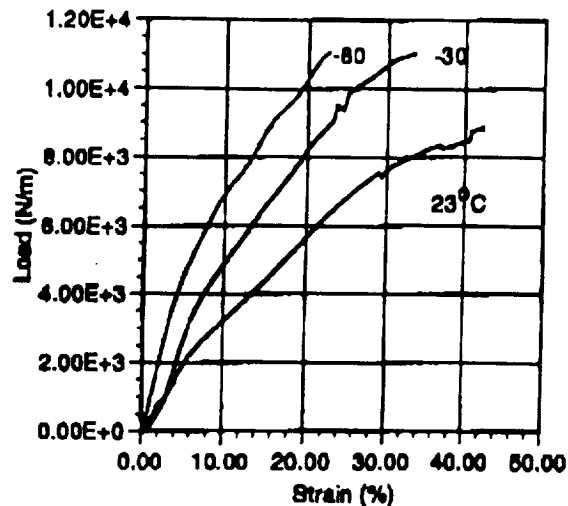


Figure (1) Effect of temperature on the mechanical properties of polyester fabric/polyester film bi-laminate in the machine direction.

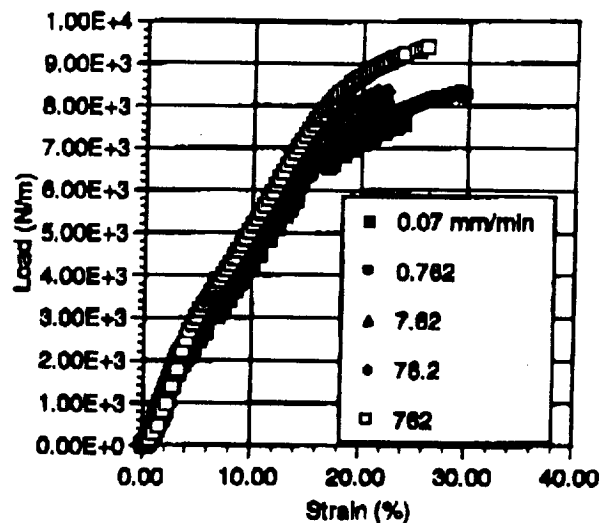


Figure (3) Effect of testing rate in the machine direction on the mechanical behavior.

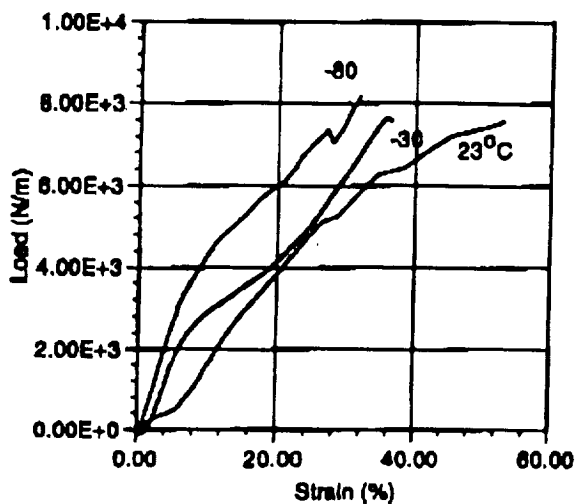


Figure (2) Effect of temperature on the mechanical properties of polyester fabric/polyester film bi-laminate in the transverse direction.

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